Army Research Laboratory

Four-Channel Threshold Detector with Optical Isolation

by Mark R. Morgenstern

ARL-TR-4683 **February 2009**

NOTICES

Disclaimers

Army Research Laboratory

Adelphi, MD 20783-1197

ARL-TR-4683 **February 2009**

Four-Channel Threshold Detector with Optical Isolation

Mark R. Morgenstern
Sensors and Electron Devices Directorate, ARL

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
February 2009

2. REPORT TYPE

3. DATES COVERED (From - To)

4. TITLE AND SUBTITLE
Four-Channel Threshold Detector with Optical Isloation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Mark R. Morgenstern

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRD-ARL-SE-DP
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-4683

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The four-channel window comparator discussed in this report is a safety switch that can be used to limit a range of test variables such as voltages, currents, temperatures or other values that can be scaled to a voltage within ±13 V. This device is simple, reliable, rugged, and requires no external control hardware or software. This module is scalable and reconfigurable to support nearly any test apparatus.

15. SUBJECT TERMS
Universal, interlock, scalable, multi-channel

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UU	26	Mark R. Morgenstern
U	U	U			19b. TELEPHONE NUMBER (*Include area code*) (301) 394-0403

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

1. Introduction

The Army Research Laboratory (ARL) has been investigating silicon carbide (SiC) semiconductor devices for use in power electronics applications including invertors, converters, high-power microwave applications, and others. Long-term stress testing of these SiC devices is required to determine suitability for power electronics applications. During testing, preventable catastrophic failures can occur due to drift in steady-state operation or transients that shift the device outside of its safe operating range. Both steady-state and transient drift are easily monitored values including temperature, on-state resistance, voltage, and current, as well as others. By measuring and reacting to shifts in these values, device damage can be minimized. These values can be converted to a voltage allowing a variety of threshold detectors to determine when the measured values fall outside of safe limits. This prevents damage by providing an interlock signal if any monitored values vary outside a preset limit. This report provides information on the design and fabrication of a threshold detector/safety control module that is versatile, simple, reliable, and rugged. Figure 1 displays a complete detector module. This feature-rich threshold detector has applicability to a wide variety of test applications through the following capabilities:

1. Upper and lower window thresholds adjustable between ±l3 V accommodating a wide range of probe or transducer output ranges and offsets.
2. Latching with 10 mV*60 ns sensitivity.
3. Channels can be set for window compare or single threshold detect on.
4. Four inputs combined by logical AND functions.
5. Low hysteresis (typically <1.5 mV> or less).
6. Low noise.
7. High common-mode rejection (between input and threshold references).
8. Most stages are designed to fail in a safe mode.
9. Optical isolation provides safety, prevents ground loops, and provides the ability to float the output stage at any voltage differential between references.
10. Powered using either DC power supplies or batteries.
11. Highly reliable through simple design and construction.
12. Easy to troubleshoot.

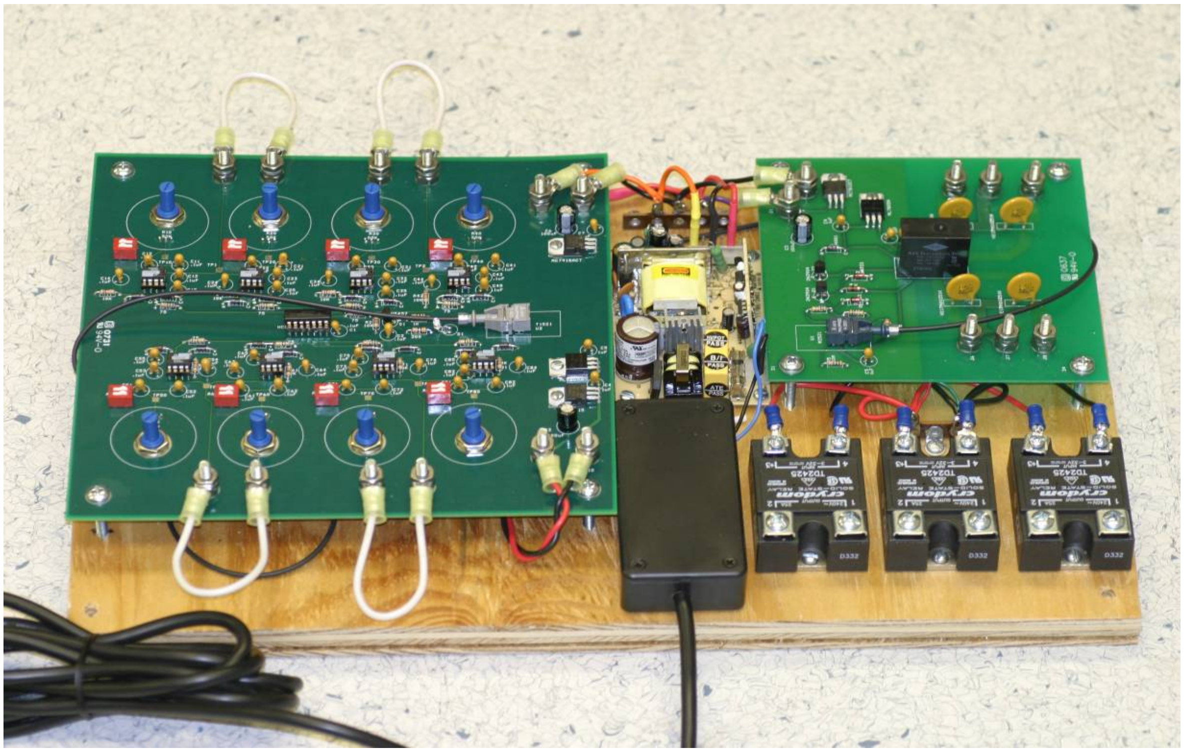

Figure 1. Complete unisolated threshold detector system with the probe board (left), relay board (right), and a shared ±15 V DC LEM power supply.

Note: Complete isolation between the probe board and the relay board provides the ability to float either board but requires two power sources isolated from one another. Solid-state relays were added (lower-right) to allow control of large power supplies that don't have built-in interlocks. These relays are controlled from the relay board's control transistor (Q2).

2. Theory of Operation

The threshold detector consists of two different electronics boards. The probe board consists of the window comparators and simple multiplexing circuitry. The relay board provides the control signals to external relays or interlocks. The comparator channels on the probe board utilize two window comparators each to compare measured values with-in preset limits. The four channels of the window comparator can be adjusted to accommodate a wide range of voltage inputs (–13 V thru +13 V), allowing use of many different types of probe and transducer outputs. Each input channel has a user-set upper and lower threshold reference. The window comparator compares the input value to its corresponding threshold limit (figure 2). In most cases, the inputs need to be impedance matched to the source due to the high input impedance of the comparators (AD-790s). Without external components, the input impedances are typically 20 Mohm || 2 pF. The comparator outputs latch low during threshold events but they can also be set to not latch

onto transient events (see schematics in appendix A). If the detection input to Ul and U2 surpasses either reference provided by Rl or R2, the respective output of Ul or U2 will be pulled low resulting in a low at the output of U3 (figure 2).

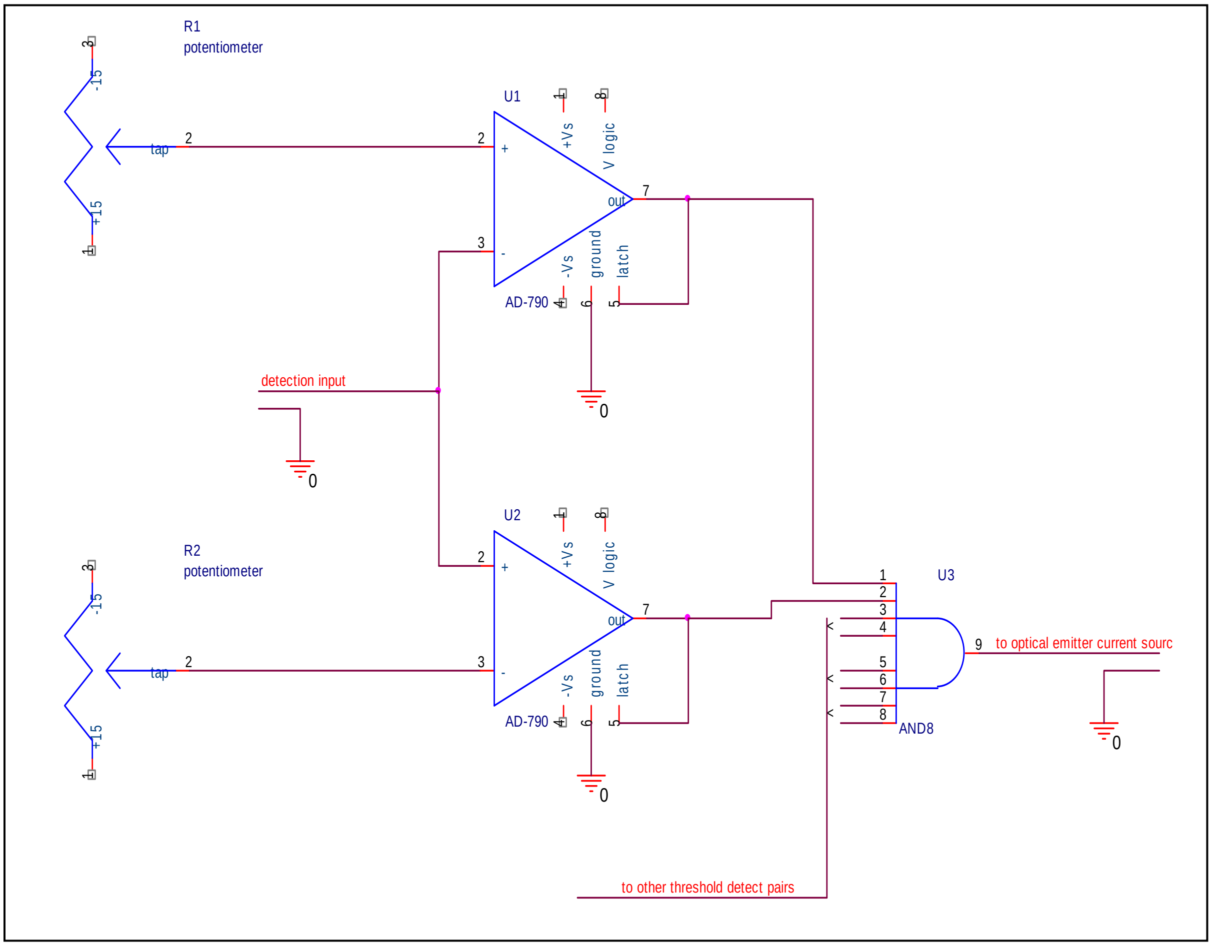

Figure 2. Basic circuit for each channel.

Note: Complete schematic can be found in appendix A.

The signals at U3's inputs are discrete digital outputs from each of the comparators (see figure 3). A low output state from the comparators indicates either a failure or an exceeded threshold. The complementary metal oxide semiconducting field-effect transistor (CMOS) AND gate U3 provides the output signal by combining the signals from each pair of comparators. Due to the CMOS AND gate limited current output a high input impedance amplifier is used to drive the optical transmitter and the light emitting diode (LED) (both of which are on during a non-failure condition). The output of U3 drives the gate of a junction field effect transistor (JFET) amplifier that controls the current for a optical transmitter. This optical transmitter allows an optical link between the probe board and the relay board, providing the ability to apply different reference voltages to each board. The differential voltage level between boards is only limited by power supply isolation. On the relay board Rl is a pull-up resistor for the optocoupler Ul, which feeds the normally high base of the bipolar junction transistor (BJT) Q1. When the optical receiver

(Ul) begins to conduct, Ql turns off. With Ql off, R4 will pull BJT Q2 high. Q2 drives the coil in relay U2. BJT's were chosen for this application due to their low input impedance, which reduces susceptibility to electromagnetic interference (EMI). These modules can be used to control power supplies that lack interlocks through the addition of solid-state relays which would be driven by Q2.

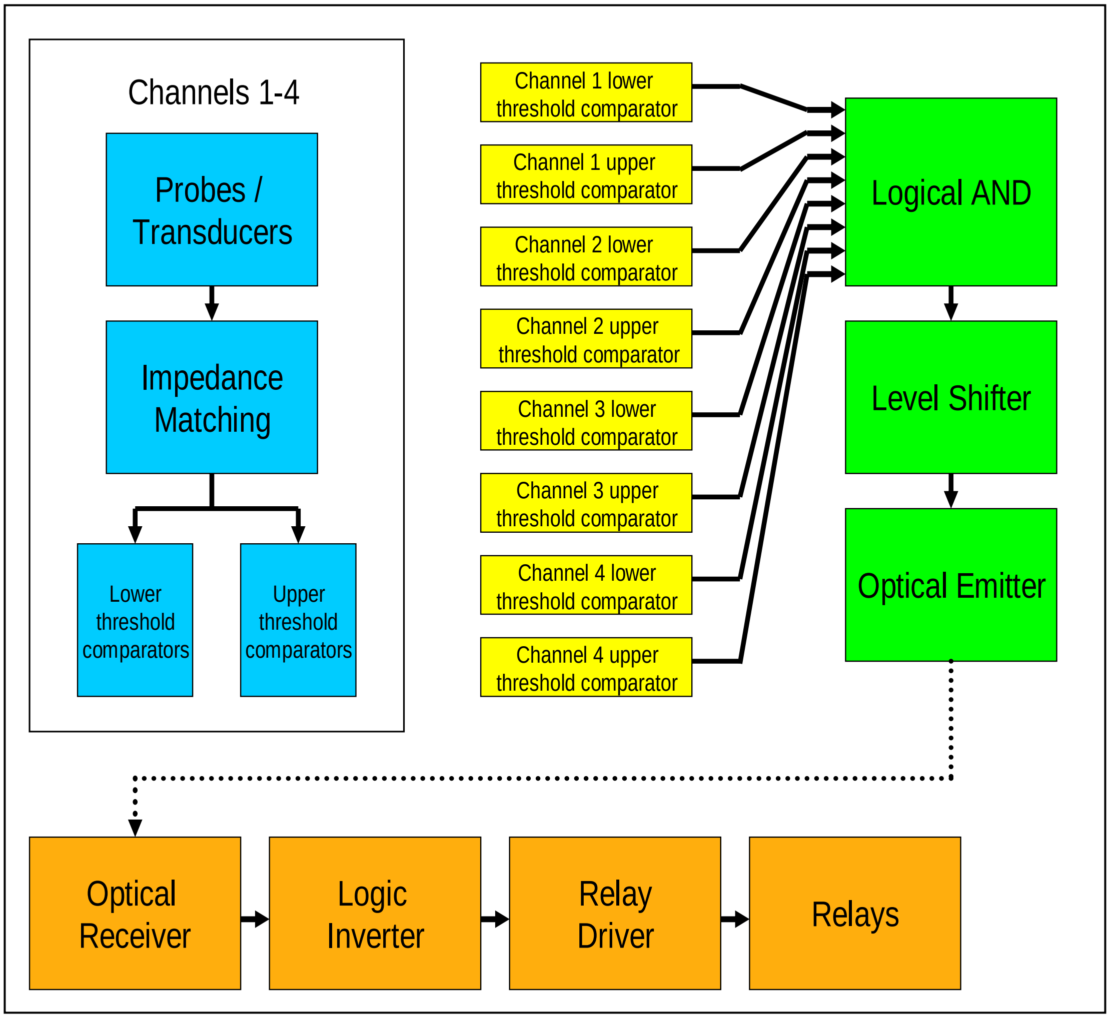

Figure 3. System signal flow diagram.

3. Board Layout

Reliability is critical for safe operation since this circuit is designed to protect other components. Good board layout is important for both the probe and relay boards to reduce cross-talk, oscillations, and transient voltage spikes that degrade input gates over a period of time. To avoid

these problems, the following practices were used in the layout of the probe board section of this system:

1. reduction of excessively long traces
2. reduction of close parallel traces
3. limited 90° turns in traces
4. large power and ground planes
5. The use of 75 ohm resistors to ensure that the effective length of the rising edges were longer than the physical length of the traces to avoid internally developed transients.

This information as well as additional information can be found in:

High-Speed Digital Design- A Handbook of Black Magic, Johnson-Graham,1993 Prentice Hall.

4. Practical Application

As demonstrated in a die attach power cycling experiment[1], the threshold detector has proven to be a reliable safety switch. The power cycling test consists of several thousand on/off cycles with durations of 5 to 30 s each. During this test, increasing diode temperature caused by device degradation or current transients causes damage to the device and die attach materials. The threshold detector prevented catastrophic failure of the SiC diodes caused by the increasing device temperature. Figure 4 displays threshold detector used in the power cycling experiment. In this experiment, the gradual temperature drift caused a drift in the forward current and forward voltage of a group of series-connected diodes (figure 5). The threshold detector monitored the anode voltage of each diode using differential probes (one diode per channel). If the voltage drifted beyond a predetermined threshold the test was shut down to prevent damage due to excessive temperature rise.

[1] Ibitayo, Dimeji; Salem, Thomas E.; Morgenstern, Mark; Koebke, Gail; Geil, Bruce R. Power Cycling Reliability Assessment of Various Die-Attach Materials. U.S. Army Research Laboratory, 2007.

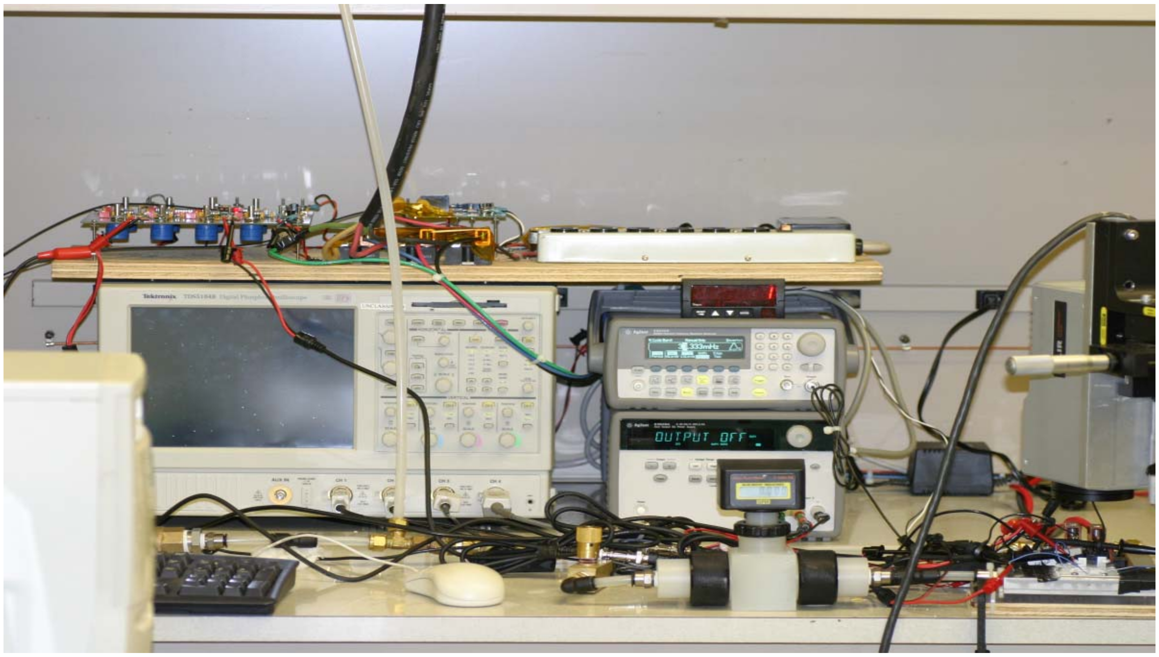

Figure 4. Threshold detector (upper left) set up to monitor anode voltages of diodes (lower right-hand corner) during long-term thermal-mechanical stress evaluation of die attach materials from power cycling.

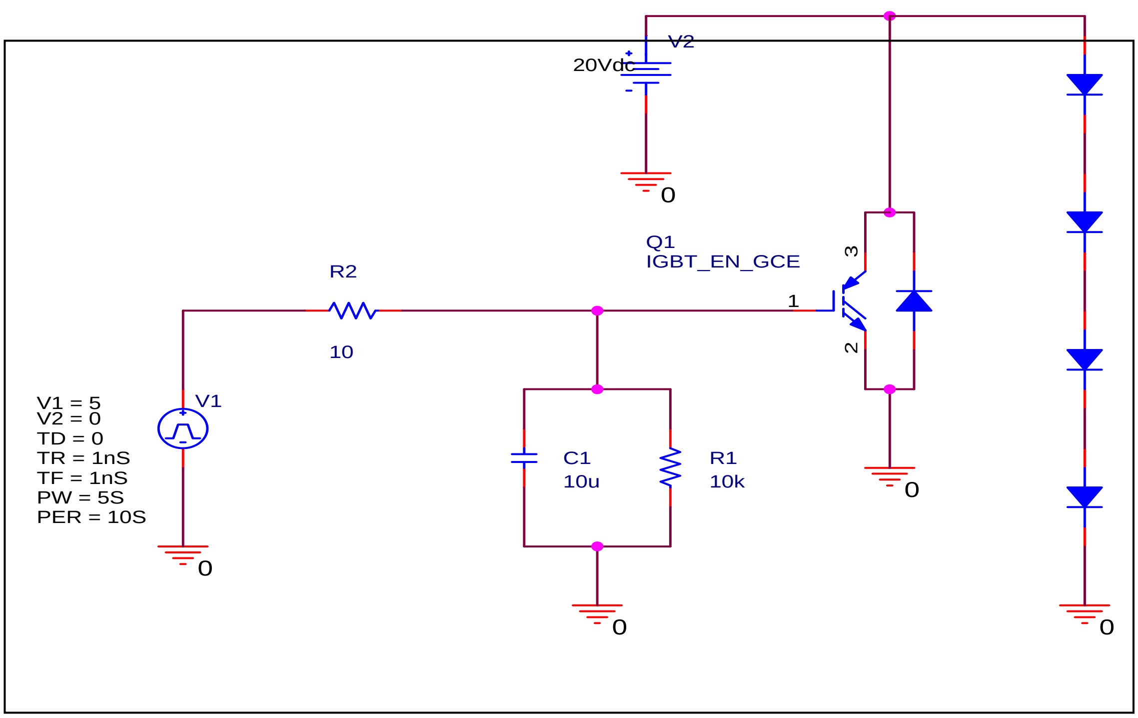

Figure 5. Die attach reliability experiment circuit.

The power supply used in this experiment was not equipped with an interlock, so three solid-state relays (one relay per phase) were used to cut off main input power to the power supply. The solid-state relay gates were controlled by the relay board. For component information, see appendix C.

The threshold detector's use in the power cycling experiment is one example of the potential of this circuit. This device can limit the voltage, current, and temperature of the test item. The detector can also be controlled with an external timer to allow timed testing. Scalable and optically isolated inputs and outputs make this threshold detector applicable for many tests where monitoring and automatic shutdown are required. For further information on use and applicability, see the Operating Procedure in appendix B.

5. Future Work

I would like to build a version of this system that is more versatile than the previous version. From using the existing threshold detectors I realized that the following improvements could be made.

1. A built-in meter that could be used to monitor and set voltages on threshold references, rather than using an external multimeter to measure test points.
2 Interchangeable and removable cards for each channel. Other cards can also be designed to plug into a slot. Current monitoring modules, temperature monitoring modules, and even timers could be plugged into slots.
3. Indicator LEDs that display if cards are installed as well as if they are in a normal or a fault condition.
4. Two enclosing chassis. (Separate chassis for Probe Monitor Board and Relay Board.)
5. British Naval Connector (BNC's) as and mini terminals at the inputs of the removable channel modules.
6. Ability to control more than one relay module with the same detector module.
7. Eight channels instead of four in each detector module.

INTENTIONALLY LEFT BLANK.

Appendix A. Schematics

The pages shown in this appendix below contain the schematics for the probe board and the relay board mentioned in this report. They are shown primarily for the benefit of any reader whose intent is to partially or fully replicate this system. The schematics may also be useful should the reader modify this design or trouble-shoot a problem with an existing module.

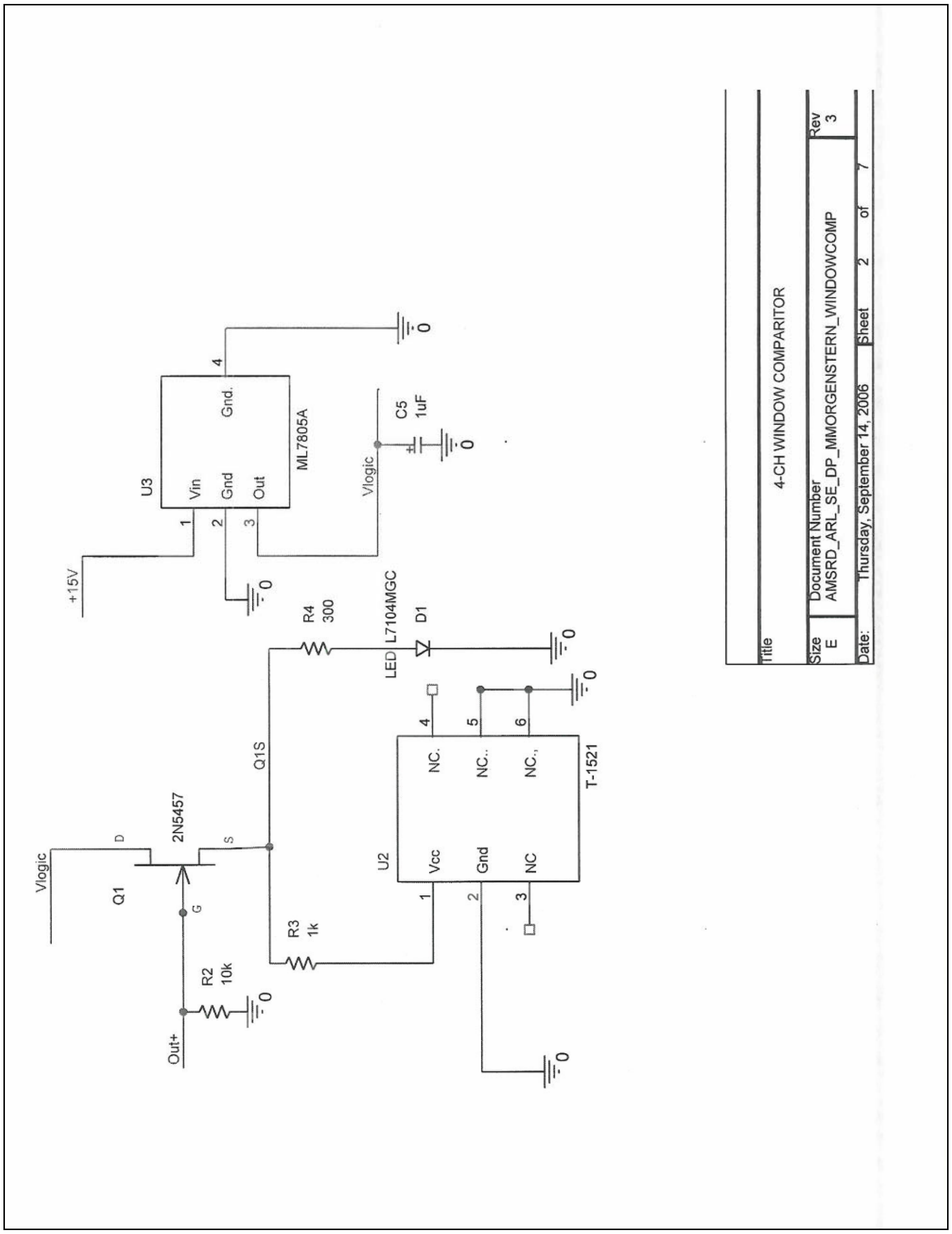

Figure A-1. Probe board LED, optical transmitter with current source Ql, and V-logic (5 V) regulator.

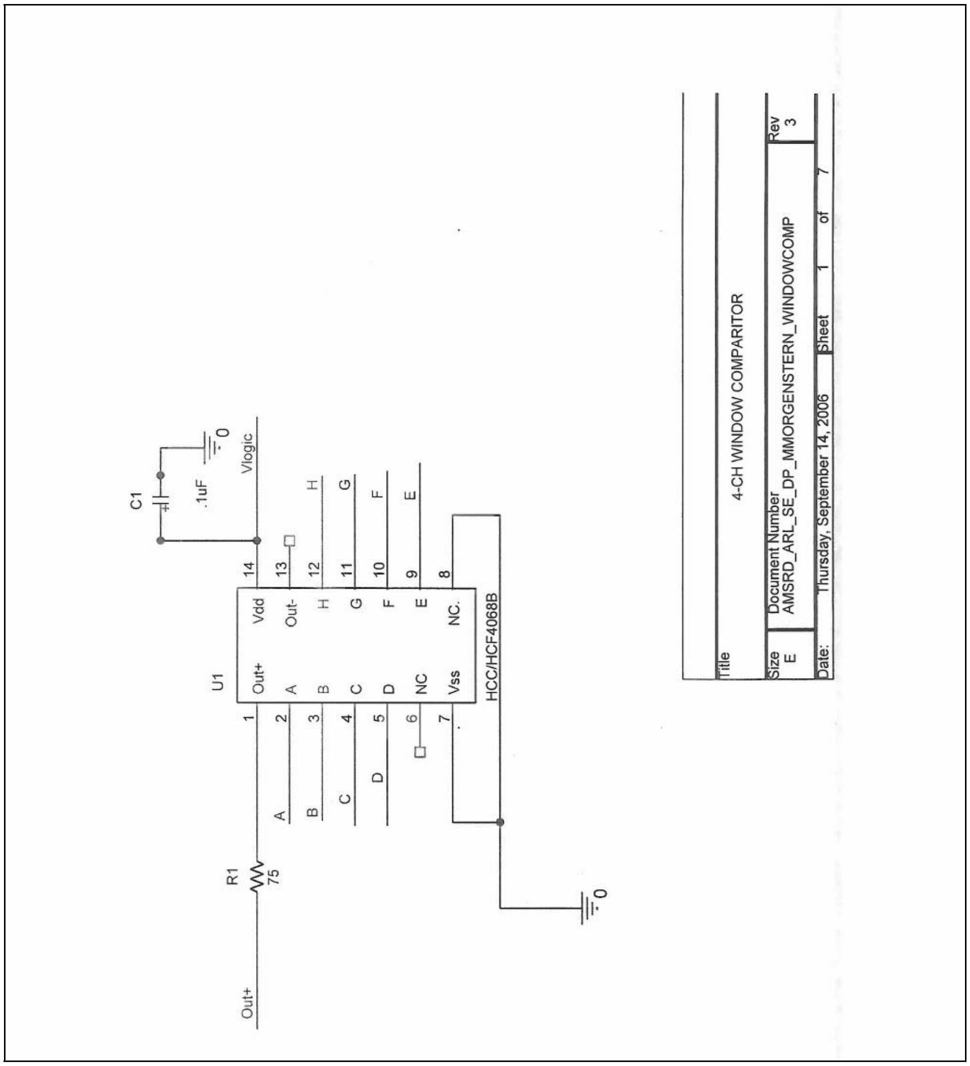

Figure A-2. AND Gate U1 on probe board.

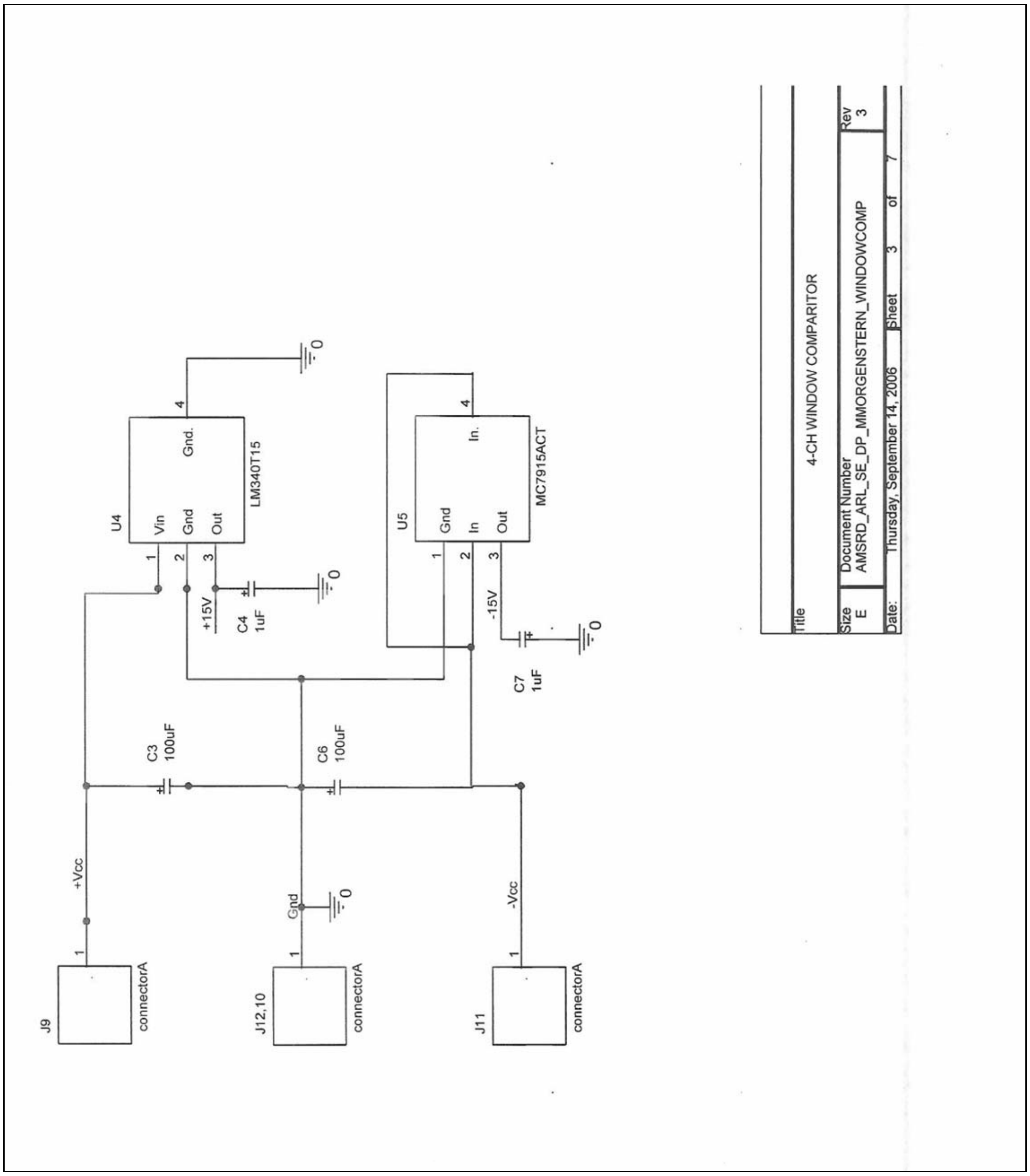

Figure A-3. Probe board ±15 V regulators with external connections.

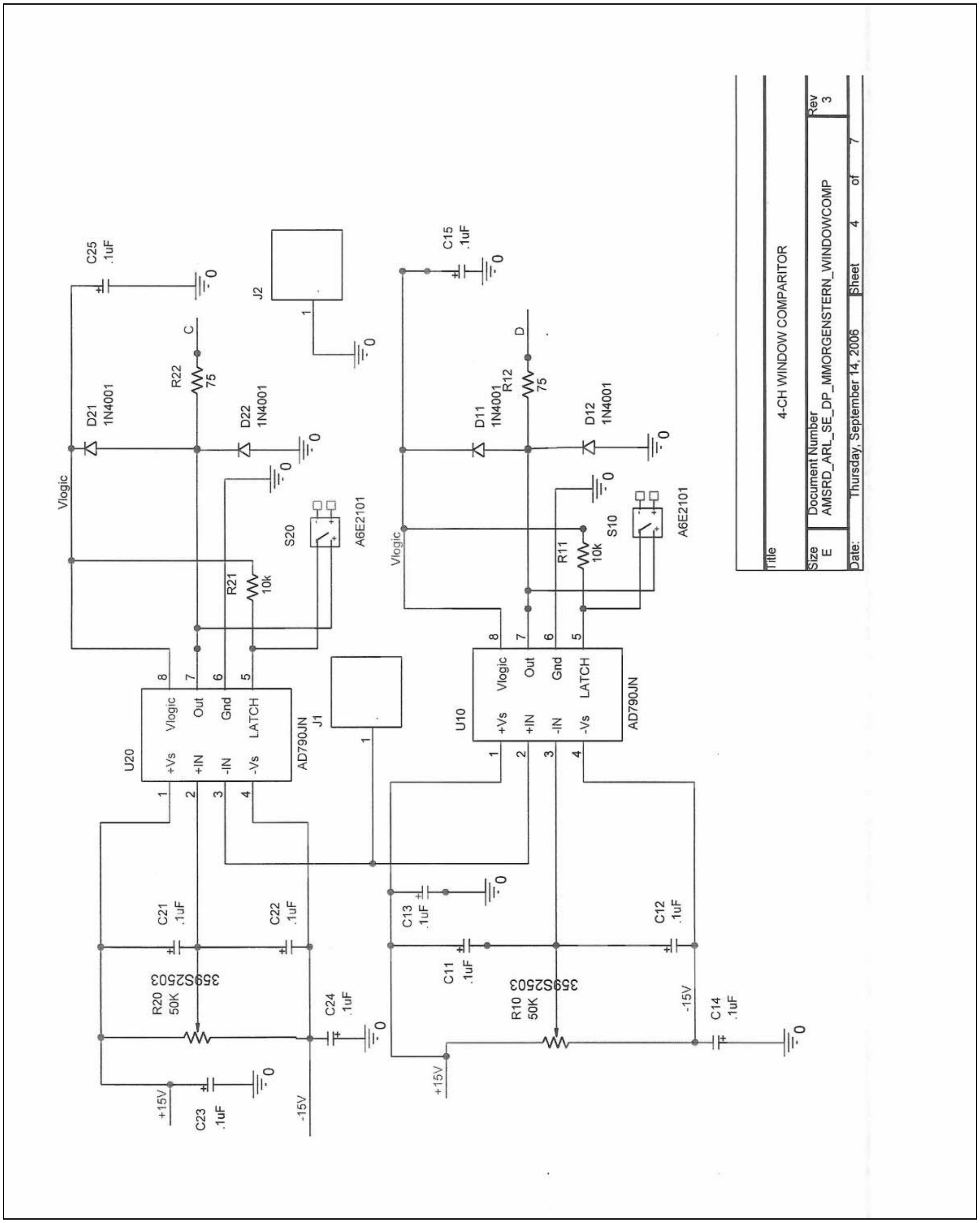

Figure A-4. Probe board circuit. Channels 1-4 are identical.

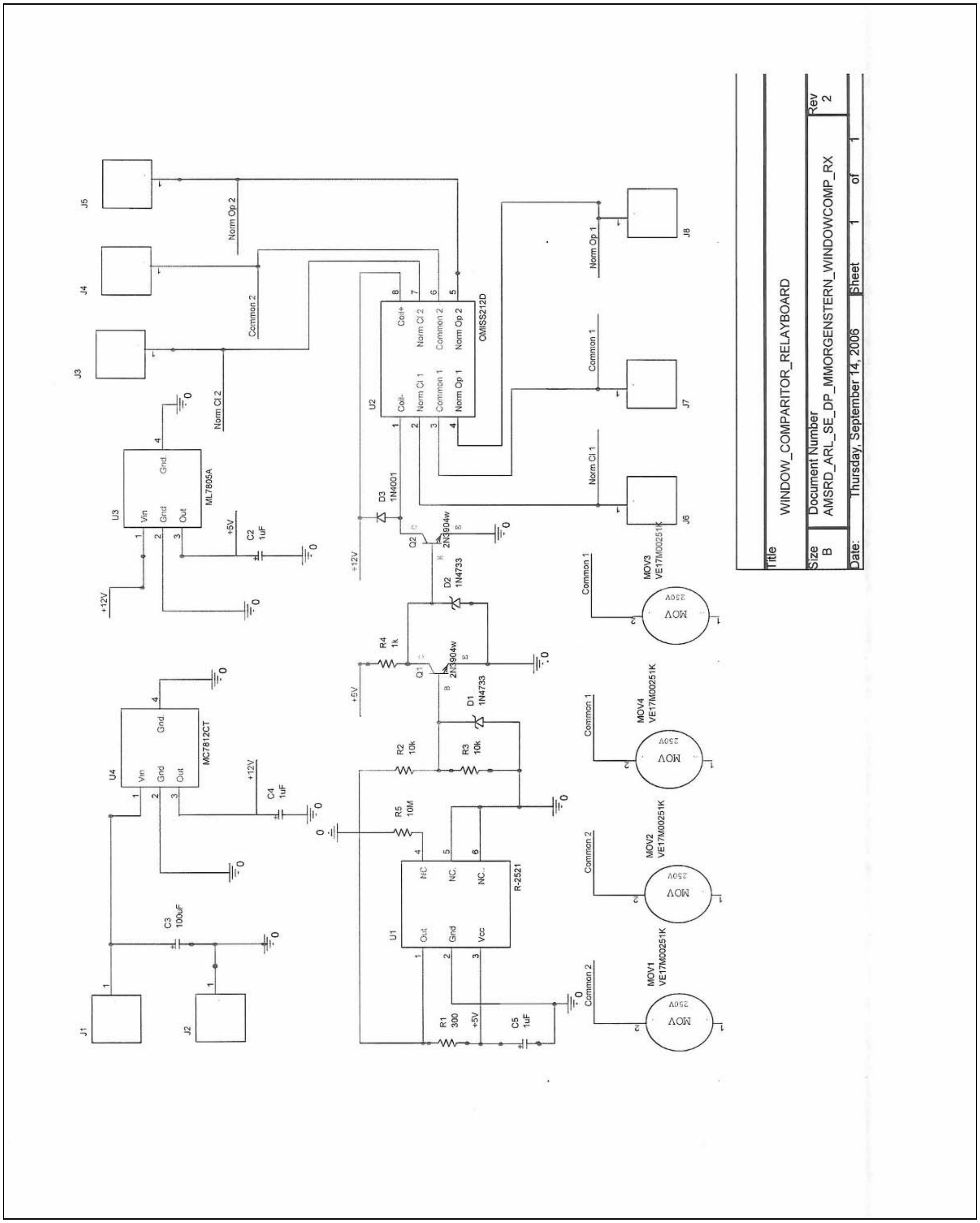

Figure A-5. Relay board complete schematic.

Appendix B. Standard Operating Procedure

This appendix, which includes figure B-1 and the following list, describe the controls, connections, test points, and operating procedure of the threshold detector.

1. Switch all dual in-line package (DIP) switches on each channel to the open position.
2. Make sure that all probe outputs are attenuated, clipped, or scaled to no more than +13.0V or no less than –13.0 V. Also know or eliminate probe offsets.
3. If applicable, filter out unwanted transients. Transient overshoot will prevent accurate shut-off thresholds if the user is trying to limit steady-state response.
4. Add shunt impedance to match the impedance of probe. If filter is being used, build impedance into output of filter. The natural impedance of each comparator channel is nearly open (20 Mohm || 2 pF). Short unused channels, as unshorted unused channels will float up to slightly above the upper threshold limit.
5. Use multimeter to measure and panel potentiometers to adjust both upper and lower thresholds. If you face the board edge towards you, the upper thresholds are always the potentiometers and test points on the left. The lower threshold adjustments are on the right. The input test point is located in the center of each channel window comparator. Make sure you are measuring between a left or right test point and any convenient ground and not the center test point.
6. Either connect the interlock to the Relay Board's relay output terminals[2] or connect power for power supply to solid-state relays. Use one per phase to a maximum of 240 V, 30 A per phase.
7. Turn power supply on but do not set up an output greater in absolute value than 0 V, 0 A.
8. Provide power to the threshold detector and relay board.
9. Check to see if the LED on Probe Board is illuminated.
10. The interlock fault on supply should also be cleared.
11. Use the small DC power supply to test upper and lower thresholds for each channel.
12. If thresholds are exceeded, the interlock should open or the supply should turn off. The LED should also go out.

[2] Make sure you use normally open terminal and common for interlocks that require a short for operation. Common is the center connector for a set of relay connections. Use multimeter to find normally open terminal. Place common multimeter lead on center point.

13. Connect probes to relevant points in the test bed.

14. Adjust power supply voltage and current. Be sure that initial conditions including transients are not beyond threshold points. The LED should be illuminated and interlock fault should be cleared.

15. Set DIP switches to the closed position where latching is required (normally you would want your power supply to latch off in a condition where a threshold is exceeded).

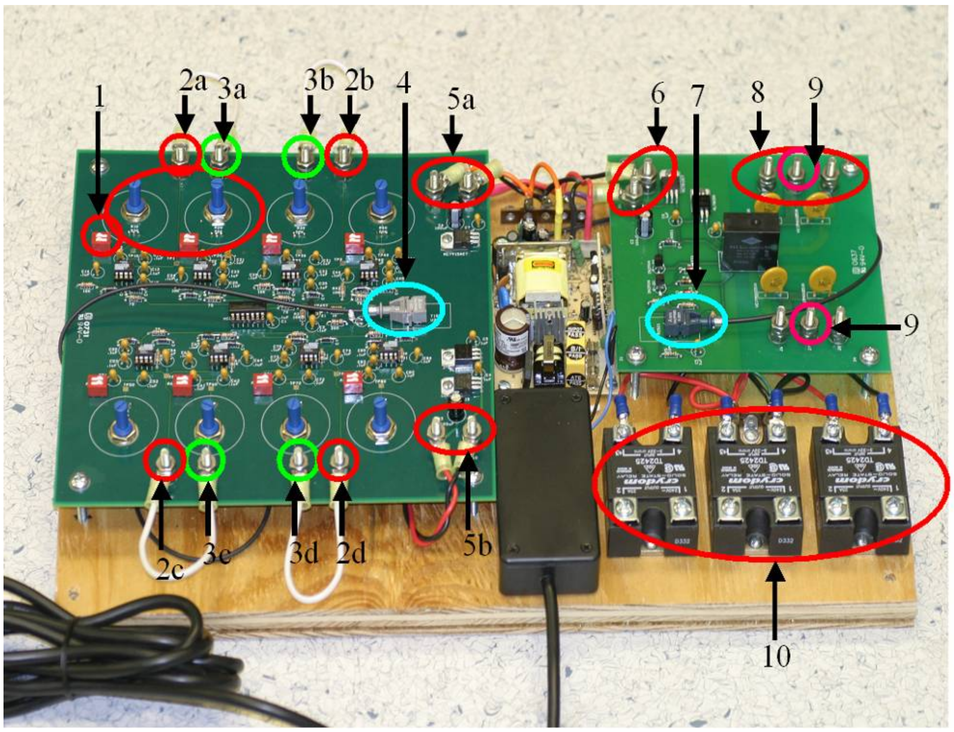

Figure B-1. Map of system interfaces.

Note: 1. Latch DIP switches
2a. channel 4 input
2b. channel 3 input
2c. channel 22 input
2d. channel 1 input
3a. channel 4 ref
3b. channel 3 ref
c3. channel 2 ref
3d. channel 1 ref
4. optical transmitter
5a. probeboard -15 V to -24 V input
5b. probeboard -15 V to -24 V input
6. relayboard +12 V to +21 V input
7. relayboard +12 V to +21 V input
8. relay contact connections
9. relay common connections
10. solid-state relays

Appendix C. Parts List

Tables C-1 through C-3 lists all components, parts, and hardware necessary to build a threshold detector as shown in figure 1.

Table C-1. Electronic components for threshold detector printed circuit boards.

Electronic Components for Printed Circuit Boards		
Part Number / Value	**Description**	**Qty**
T-1521	Fiber Optic Transmitter	1
lKohm 1l4W	Carbon or Metal Film Restore	2
10Kohm 1l4W	Carbon or Metal Film Restore	11
2N5457	JFET	1
300ohm 1AW	Carbon or Metal Film Resistor	2
L7104MGC	Light Emitting Diode	1
ML78O5A5V	Regulator	2
1uF tantalum 35 V	Capacitor	6
75ohm 1l4 W	Carbon or Metal Film Resistor	I
.1 uF tantalum 35V	Capacitor	37
HCC / HCF 40688	CMOS 8 input NAND / AND	1
100uF aluminum 35 V	Capacitor	3
1M340T15	1 5 V, 1 A TO –220 Regulator	1
MC7915ACT	neg15 V, 1 A TO –220 Regulator	1
35952503	50 Kohm, 10-turn Panel Potentiometer	8
AD79OJN	Precision, Fast Comparator with Latching and Level Shifter	8
A6E2 101	2-DlP Single Pole Double Throw Rocker Switch	8
1 N4001	General Purpose Diode	17
MCTB 12CT	12 V, 1 A TO –220 Regulator	1
R-2521	Fiber Optic Receiver	1
VE17M00251 K	250V MOV	4
10Mohm 1l4W	Carbon or Metal Film Resistor	1
1 N4733	5.1 V Zenor Diode	2
2N3904w	General Purpose NPN Transistor	2
OMISS2 12D	12V DPDT Relay	1

Table C-2. The two printed circuit boards in the threshold detector system.

	Printed Circuit Boards	
Part Number/Value	**Description**	**Qty**
	Probeboard 1	1
	Relayboard	1

Table C-3. Other components required to build the threshold detector.

	Peripheral Components	
Part Number/Values	**Description**	**Qty**
	#10 washers	56
	#10 lock washers	28
	#10-32 hex nuts	56
	#10-32 x 1.25" screws	28
18,16, or 14 gauge	hookup wire	
	external power supplies or batteries	2or3
no more than 30'	fiber optic cable	1
	filters if or as needed	
	probes if or as needed	
	scaling switches or relays as needed	
	shunt impedance for channel inputs	
	termrnal lugs	
	solder	1 roll

No. of Copies	Organization
1 PDF	ADMNSTR DEFNS TECHL INFO CTR ATTN DTIC OCP 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	DARPA ATTN IXO S WELBY 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1 CD	OFC OF THE SECY OF DEFNS ATTN ODDRE (R&AT) THE PENTAGON WASHINGTON DC 20301-3080
1	US ARMY RSRCH DEV AND ENGRG CMND ARMAMENT RSRCH DEV AND ENGRG CTR ARMAMENT ENGRG AND TECHNLGY CTR ATTN AMSRD AAR AEF T J MATTS BLDG 305 ABERDEEN PROVING GROUND MD 21005-5001
1	US ARMY INFO SYS ENGRG CMND ATTN AMSEL IE TD F JENIA FT HUACHUCA AZ 85613-5300
1	COMMANDER US ARMY RDECOM ATTN AMSRD AMR W C MCCORKLE 5400 FOWLER RD REDSTONE ARSENAL AL 35898-5000
1	US GOVERNMENT PRINT OFF DEPOSITORY RECEIVING SECTION ATTN MAIL STOP IDAD J TATE 732 NORTH CAPITOL ST NW WASHINGTON DC 20402

No. of Copies	Organization
1	US ARMY RSRCH LAB ATTN AMSRD ARL CI OK TP TECHL LIB T LANDFRIED BLDG 4600 ABERDEEN PROVING GROUND MD 21005-5066
1	DIRECTOR US ARMY RSRCH LAB ATTN AMSRD ARL RO EV W D BACH PO BOX 12211 RESEARCH TRIANGLE PARK NC 27709
22	US ARMY RSRCH LAB ATTN AMSRD ARL CI OK PE TECHL PUB ATTN AMSRD ARL CI OK TL TECHL LIB ATTN AMSRD ARL SE DP A OGUNNIYI ATTN AMSRD ARL SE DP J HOPKINS ATTN AMSRD ARL SE DP L EVERHEART ATTN AMSRD ARL SE DP M MORGENSTERN (10 COPIES) ATTN AMSRD ARL SE DP R GREEN ATTN AMSRD ARL SE DP T GRIFFIN ATTN AMSRD ARL SE DP T SALEM ATTN AMSRD-ARL-SE-DP B GEIL ATTN AMSRD-ARL-SE-DP C SCOZZIE ATTN AMSRD-ARL-SE-DP D IBITAYO ATTN IMNE ALC IMS MAIL & RECORDS MGMT ADELPHI MD 20783-1197
Total:	31 (29 HC, 1 CD, 1 PDF)

INTENTIONALLY LEFT BLANK.